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Investigation of Fiber Distribution in Concrete Batches Discharged from Ready-Mix Truck

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Abstract: This paper presents the findings of an investigation of the fiber content variations in concrete being discharged from a ready-mix truck at the construction site. Concrete samples were extracted from the truck drums at the beginning, middle and end of discharge. Subsequently, fibers in each sample were separated from the concrete, and weighed. Presumably, synthetic macro fibers will float towards the top, i.e. towards the drum opening, of the inclined, revolving truck-drum, while, on the other hand, steel fibers will tend to gravitate towards the lower parts of the mixer drum. Accordingly, the discharge batch, containing synthetic macro fibers, will contain a higher amount of synthetic fibers per unit volume at the start of discharge than the average unit volume fiber content of the mix, and the content will gradually decrease further down the batch. The discharge batch of steel fiber concrete will contain fewer fibers per unit volume at the start of discharge than the average unit volume fiber content of the mix, and the content should gradually increase further down the batch. The correctness of the foregoing is partly confirmed. A certain percentage of the truck loads did not comply with the proposed requirements, mainly steel fiber reinforced batches, indicating the necessity of a code or guideline amendment. A change in the Norwegian shotcrete directive was made in 2011, based upon experimental research work (2010), which, in combination with the subsequent University of Life Sciences report (2012), constitutes the foundation of this article.

Keywords: ready-mix, truck-drum, concrete, fibers, distribution.

1. Introduction

1.1 Purpose and Applicability of These Investigations

Concrete structures are crack-prone. This is particularly true for slabs on grade. Attempts at crack control are directed at reducing the width of each particular crack, in spite of the tradeoff of increasing the number of cracks. The durability of concrete is impaired by cracks, as they provide a path for the transportation of potentially harmful liquids and gases. Cracks of small width reduce the deterioration risk due to diminished influx of potentially damaging substances (Concrete Construction Staff 1997; The Concrete Society 2013). Narrow cracks are also preferable for aesthetic reasons. Furthermore, the mechanisms of concrete self-healing will only mend cracks of small breadth (Van Tittelboom et al. 2013). It is generally acknowledged that fibers do limit the widths of cracks caused by plastic and drying shrinkage. The higher the amount of fibers, the more effective is the crack limitation. Accordingly, to achieve uniform crack control throughout the concrete pour, the fibers should be evenly distributed. Also, irregular fiber distribution may give varying workability, e.g. pumping suitability, and affect separation tendencies.

1.2 Proposed Limits on Fiber Content in Samples

The following minimum fiber content limits, based upon the requirements by *Deutscher Ausschuss für Stahlbeton* (German Committee for Structural Concrete 2008), were proposed by the Norwegian Concrete Association (Norsk Betongforening 2010) for inclusion in the relevant Norwegian Building Code:

- Average of 3 samples: Minimum 90 % of specified fiber content
- Any individual sample: Minimum 85 % of specified fiber content

However, if a restriction on the *maximum* fiber content is not to be implemented, a ready-mix producer may add a sufficient amount of fibers, above the amount specified, to provide a “buffer” to make sure not to risk rejection of a load. This could result in negative effects, e.g. excessive workability variations, locally higher amounts of entrapped air, variations in compressive strength within the structure,

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and possibly more bleeding/segregation (W. R. Grace Co., Grace Concrete Products 2011).

Accordingly, subsequent to the completion of the work done by Nikolaisen (2010), which constitute the initiation of this report, maximum fiber content limits in shotcrete were proposed by the Norwegian Concrete Association for inclusion in the relevant Norwegian Code (Norwegian Concrete Association Publication No. 7 2011; Sørensen 2012). In addition, the minimum contents were lowered by 5 %, i.e. to 85 % and 80 % respectively for the average of 3 samples and for any individual sample.

- Average of 3 samples: Minimum 85 % of specified fiber content, maximum 115 %
- Any individual sample: Minimum 80 % of specified fiber content, maximum 120 %

An investigation of possible compliance with the above requirements, summarized in Table 1, is carried out as part of this research project.

1.3 Hypothesis

Synthetic macro fibers will float towards the top, i.e. opening, of the inclined, revolving, mixing—truck drum. Accordingly, the concrete discharge batch will contain a higher amount of synthetic fibers per unit volume in the beginning of discharge than the average unit volume fiber content of the mix, and the content will gradually decrease further down the batch. Steel fibers, on the contrary, will tend to sink towards the bottom parts of the drum, thus causing the initial discharge samples to contain fewer steel fibers per unit volume than later samples (Nikolaisen 2010).

2. Methods

2.1 Procedure in this Experimental Series for Adding Fibers from Bags to Truck-drum

Common truck mixer rotation procedure, and fiber addition routine, in Norway: "the drum is rotated at slow agitation speed, 2–6 revolutions per minute, while underway to the construction site, with no fibers in the batch. Upon arrival at the delivery site, with the truck stationary, an additional 5 min of rapid rotation, while the fibers are being added, 12–18 revolutions per minute, is undertaken. Then the drum is run at 12–18 revolutions per minute for 5 min prior to discharge. The rate of steel fiber addition should not exceed 60 kg/min, and the concrete slump must be at least 120 mm".

The addition rate and time of addition of the synthetic fibers were not considered significant (W. R. Grace Co., Grace Concrete Products 2011). The drum has to be rotated rapidly, 12–18 revolutions per minute, for a minimum duration of 5 min following the addition of synthetic fibers. The amounts of fibers added are normally not weighed, neither the steel nor the synthetic fibers, but the sacks are counted, and rounded off to the nearest half sack (Nikolaisen 2010). Refer to the Appendix regarding truck delivery-slip information on batches.

The fiber addition- and mixing—procedures, including truck drum speeds, were kept the same throughout the test series'. To investigate any possible influence of mixing procedures, like drum speeds and duration of mixing, on fiber distribution, was considered to be outside the scope of this research work.

The test procedures have evolved throughout these investigations from discussions, reviewing previous test methods and other research reports, standards, directions and recommendations. A 10 l test sample volume seemed to be nearly ideal, and the fiber segregation methods do separate all fibers from the test samples (Nikolaisen 2010). The Truck 4 (ref. Table 3) steel fiber samples were taken from the discharge end of the pump-hose, and the figures indicate that the pumping process apparently did not cause a change in fiber-content.

2.2 Sources of Errors

No measurements of air content were done, neither were any tests on slump or flow performed at the delivery-site. Slump-test results from the batch-plant are listed in the "Appendix". Even if the rinsing of fibers prior to weighing was done as thoroughly as reasonably possible, slight residues, barely visible, may have affected the results, i.e. the recorded weight of synthetic fibers. The duration of mixing at the batch-plant has neither been specified nor recorded. The distance between batch-plant and delivery-site was 25 km (batches destined for steel fiber addition at delivery site) and 6.5 km (batches destined for synthetic macro fiber addition at the delivery site). However, the hauling-time was not recorded, and could vary due to e.g. traffic jams. This could affect the consistency of the concrete at the job-site. Considerable variations were noticed in the revolving speed of drums during transport, and also while mixing after the addition of fibers at the delivery site. These factors may have had an effect on the distribution of fibers in the concrete mass.

3. Experimental Work and Results

3.1 Steel Fiber Batches

Fibers with hooked ends have been commonly used in Norway for decades. The steel fiber type utilized in this research is described by Figs. 1, 2 and Table 2.

Table 1 Proposals for fiber content to be investigated.

	Average of 3 samples	Any individual sample
Proposal I	Minimum 90 % of specified fiber content. No maximum	Minimum 85 % of specified fiber content. No maximum
Proposal II	Minimum 85 % of specified fiber content. Maximum 115 %	Minimum 80 % of specified fiber content. Maximum 120 %

Fig. 1 Steel fiber (Nikolaisen 2010).

Fig. 2 Steel fiber dimensions, ref. Table 2.

Upon arrival of the ready-mix truck at the construction site, Vestby Outlet Shopping Center, south of Oslo, next to Highway E6, 25 kg/m^3 of steel fibers were added by emptying full bags into the revolving truck-drum. The concrete was to be placed by pumping. Only full bags were used to avoid variations in the added fiber content. The steel fibers were added at the rate of approximately 45 kg/min, while the truck-drum was rotating at 12–18 revolutions per minute. Then the drum was run at 12–18 revolutions per minute for 5 min. Thereafter, three 10 l samples were taken out during discharge from each of 15 truck-loads: one at the start of discharge, one about midway thru, and one at the end. The fibers where subsequently extracted magnetically from the fresh concrete samples by using an Arcelor Mittal Dosometer, and then weighed. The results are listed in Table 3, and displayed in Figs. 3 and 4 as a scatterplot and a box-plot respectively.

The scatter-plot of results, Fig. 3, indicate that the smallest discrepancy from the specified fiber content occurs at the beginning of the truck discharge, increasing at the middle and being the largest at the end of dispatch.

The box-plot diagram Fig. 4, of the steel fiber weighing, visualizes the results presented in Table 3 and by the scatter-plot, Fig. 3.

The vertical lines at the top and bottom of each box indicate the limits of fiber amounts. The circle indicate the average value and the horizontal line represents the median value.

3.2 Synthetic Fiber Batches

Use of synthetic fibers in Norway started in 2003 and was initially applied in shotcrete, and later as shrinkage reinforcement, particularly in slabs on grade, mainly because synthetic fibers do not corrode, hence, not causing rust-marks. Synthetic fibers have proven to be more cost-effective than steel fibers (Nikolaisen 2010). The synthetic fibers utilized in this work are featured in Fig. 5 and Table 4.

Upon arrival of the ready-mix truck at the construction site, Økern-Sinsen tunnel in Oslo, 7 kg/m^3 of synthetic macro fibers were added to the truck-drum by emptying full sacks into the revolving drum. Only full bags were used, to eliminate variations in added fiber content. The batch was to be placed by shotcreting. Fibers were added while the truck-drum was rotating at 12–18 revolutions per minute, and thereafter further mixed into the batch during approximately 70 revolutions of the drum at 12–18 revolutions per minute for a duration of 5 min. Three 10 l samples were taken out during discharge from each of 8 truck-loads: one at the start of discharge, one about midway thru, and one at the end. The fibers were separated from the concrete by washing out and then weighed. The results are listed in Table 5, and displayed in Figs. 6 and 7, as a scatterplot and a box-plot respectively.

The scatter-plot of results, Fig. 6, indicates, contrary to the steel fiber results, that the largest discrepancy from the specified fiber content occurs at the beginning of the truck discharge, decreasing at the middle and being the least at the end of dispatch.

Table 2 Steel fiber technical data (Nikolaisen 2010).

Characteristics	Material property
Material	Steel
Length	50 mm
Diameter	1 mm ± 0,04 mm
Tensile strength	1,100 MPa
θ	45° (min. 30°)
Configuration	End hook
l	1–4 mm
h	1.8 mm (+1/−0 mm)
Fibers per kg	3,100
Specific gravity	Approx. 7.85
Young's modulus	200 GPa

Table 3 Results, sample content at start, middle and end of truck discharge of steel fiber reinforced concrete, 250 g/10 l = 25 kg/m^3.

Truck load no.	Start kg/m^3	Middle kg/m^3	End kg/m^3	Average kg/m^3	% of added
1	216.0	207.0	235.0	219.3	87.7
2	253.0	205.0	300.0	252.7	101.1
3	247.0	227.0	242.0	238.7	95.5
4	242.0	250.0	241.0	244.3	97.7
5	256.0	198.0	356.0	270.0	108.0
6	247.0	196.0	265.0	236.0	94.4
7	242.0	246.0	254.0	247.3	98.9
8	239.0	210.0	261.0	236.7	94.7
9	264.0	251.0	216.0	243.7	97.5
10	249.0	237.0	244.0	243.3	97.3
11	258.0	244.0	216.0	239.3	95.7
12	238.0	225.0	307.0	256.7	102.7
13	230.0	240.0	255.0	241.7	96.7
14	258.0	228.0	336.0	274.0	109.6
15	242.0	285.0	192.0	239.7	95.9
Average	245.4	229.9	261.3	245.6	**98.2**
Portions of the amounts added to the batch	98.2 %	92.0 %	104.5 %	98.2 %	98.2%

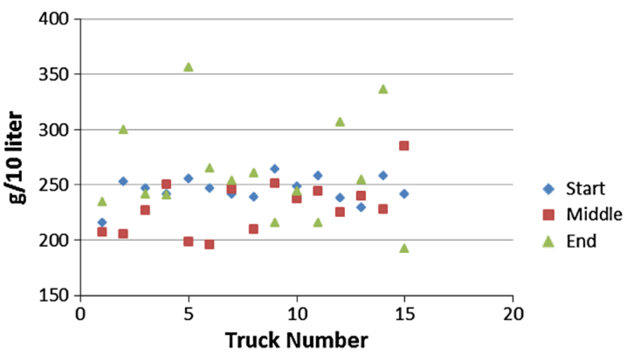

Fig. 3 Plotted results from steel fiber weighing, ref. Table 3.

A box-plot diagram Fig. 7, of the synthetic macro fiber weighing, visualizes results as they are presented in Table 5 and by the scatter-plot, Fig. 6.

The vertical lines at the top and bottom of each box in Fig. 7 indicates the limits of fiber amounts. The circle indicates the average value and the horizontal line represents the median value.

4. Summary of Results

The percentages of single samples and average of 3 samples not complying with the proposed limits on fiber content are listed in Table 6. The steel fiber

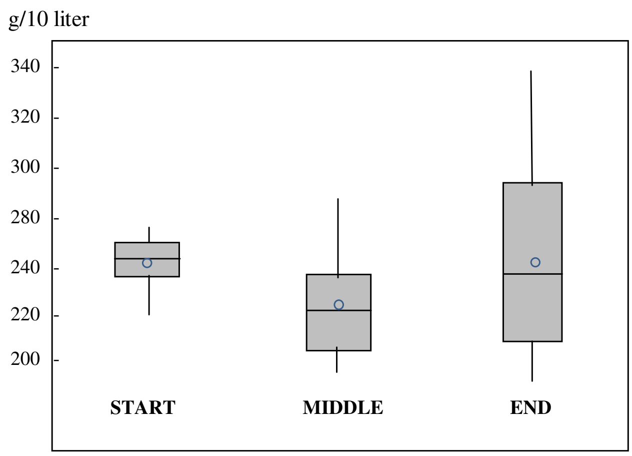

Fig. 4 *Box-plot* presentation of steel fiber weighing, ref. Table 3.

contents in a number of ready-mix truck loads did not comply with neither of the two alternative code amendments proposed.

All synthetic macro fiber concrete tests did meet the Proposal I requirement, and only one synthetic fiber truck-load did not comply with the Proposal II requirements, by yielding one single test-sample containing more fibers than would be permitted. The percentages of truck loads not complying with the proposed limits on fiber content are listed in Table 7. The amounts of fibers used, 25 kg/m^3 in the steel fiber reinforced concrete, and 7 kg/m^3 in the synthetic macro fiber reinforced concrete, caused no problems, neither regarding casting in place nor compaction.

5. Conclusions

A certain percentage of the truck loads did not comply with the proposed fiber content requirements, mainly steel fiber reinforced batches, indicating the necessity of a code or guideline amendment. Based on the test results and observations, the following conclusions may be drawn:

- The steel fiber contents in a number of ready-mix truck loads did not comply with neither of the two proposed alternative code amendments, implying that adjustments in batching procedures may be advisable regarding steel-fiber mixing routines.
- All synthetic macro fiber concrete tests did meet the Proposal I requirement, and only one truck-load did not comply with Proposal II requirements, by yielding one test-sample containing more fibers than would be permitted.
- Indications are that the steel fiber concrete truck loads contained fewer fibers at the start of discharge than at the end of discharge. However, the only statistical significance was found between the fiber content being higher at the end of discharge than in the middle of discharge. Even if the number of tests is not sufficient to draw a definite conclusion, this research work does indicate higher fiber content at the end of discharge.

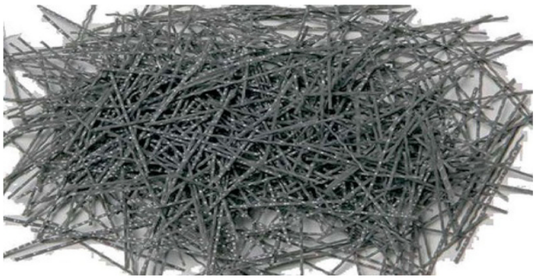

Fig. 5 Synthetic macro fibers (Nikolaisen 2010).

Table 4 Synthetic macro fiber data (Nikolaisen 2010).

Characteristics	Material property
Base resin	Polyolefin
Length	48 mm
Tensile strength	550 MPa
Surface texture	Embossed
Fibers per kg	>35,000
Specific gravity	0.90–0.92
Young's modulus	10 GPa
Melting point	150–165 °C
Ignition point	>450°

Table 5 Results, sample content at start, middle and end of truck discharge of synthetic macro fiber reinforced concrete, 70 g/10 l, equivalent to 7 kg/m^3.

Truck load no.	Start	Middle	End	Average	% of added
1	81.0	71.0	74.0	75.3	107.6
2	63.0	65.0	75.0	67.7	96.7
3	84.0	75.0	72.0	77.0	110.0
4	83.0	79.0	73.0	78.3	111.9
5	70.0	63.0	76.0	69.7	99.5
6	79.0	75.0	69.0	74.3	106.2
7	98.0	78.0	70.0	82.0	80.0
8	82.0	76.0	82.0	80.0	114.3
Average	80.0	72.8	73.9	75.5	107.9
Portions of the amounts added to batch	114.3 %	103.9 %	105.5 %	107.9 %	107.9 %

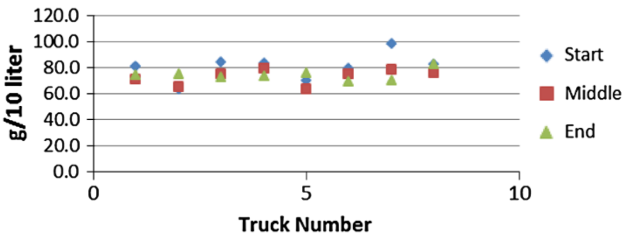

Fig. 6 Plotted results from synthetic fiber weighing, ref. Table 5.

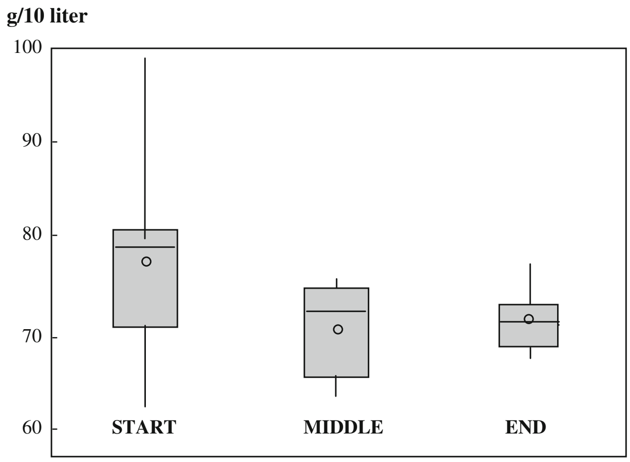

Fig. 7 *Box-plot* presentation of synthetic macro fiber weighing, ref. Table 5.

- The apparent indication of the synthetic macro fiber concrete containing more fibers at the start of discharge than towards the end of discharge is neither supported nor rejected by statistical significance computations, as the number of tests carried out are too low for a definite conclusion to be drawn.
- The concrete with the amounts of fibers used, 25 kg/m^3 in the steel fiber reinforced concrete, and 7 kg/m^3 in the synthetic macro fiber reinforced concrete, had good workability. No clustering of fibers was observed. The amounts of fibers used caused no problems, neither regarding casting in place nor compaction, which basically agrees with other findings (The Concrete Producer Magazine 2011; Hauck 2004).
- The code and/or guideline amendment according to Proposal II seems justified.
- Amendment effectuated: The Norwegian Concrete Society (*Norsk betongforening*) and The Norwegian Public Roads Administration (*Statens vegvesen*) did, in 2011, on the basis of the origin of this article (Nikolaisen 2010), include the Proposal II restrictions as part of guidelines concerning e.g. rock stabilization applications, such as in tunnels (Norwegian Concrete Association Publication No. 7 2011; Hauck 2004). The guidelines includes directions for adjustments of sample fibre content if concrete air content exceeds 4 %, as well as instructions on where in the batch discharge to collect samples.

Table 6 Percentage of single samples and average of 3 samples not complying with the proposed limits on fiber content.

	Proposal I Average of 3 samples: Minimum 90 % Any individual sample: Minimum 85 %		Proposal II Average of 3 samples: Minimum 85 % Any individual sample: Minimum 80 % Average of 3 samples: Maximum 115 % Any individual sample: Maximum 120 %			
	% Below min. of average of 3 samples	% Below min. of single samples	% Below min. of average of 3 samples	% Below min. of single samples	% Above max. of average of 3 samples	% Above max. of single samples
Steel fibers	6.7	13.3	0	6.7	0	4.4
Synthetic macro fibers	0	0	0	0	0	2.2

Table 7 Percentage of truck loads not complying with the proposed limits on fiber content.

	Proposal I Average of 3 samples: minimum 90 % Any individual sample: minimum 85 %	Proposal II Average of 3 samples: minimum 85 % Any individual sample: minimum 80 % Average of 3 samples: maximum 115 % Any individual sample: maximum 120 %
Steel fibers	40 (6 truck-batches out of 15)	40 (6 truck-batches out of 15)
Synthetic macro fibers	0	13 (One truck-batch of 8)

- Suggested further research:
  Investigation of the influence of mixing procedures, drum speeds, duration of mixing, time lapse between the addition of fibers and discharge, and placing methods.

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Appendix

See Table 8.

Table 8 Truck delivery slip information.

Truck number	Date	D_{max}, mm	Coarse aggregate reduction	Slump, mm	Delivery distance, km	Fiber type	Fiber content specified, kg/m^3	Mix type	Temp, °C	W/C ratio
1	7.9.09	16	28 %	210	5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
2	16.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
3	16.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
4	16.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
5	16.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
6	16.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
7	17.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
8	17.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
9	17.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
10	17.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54

Table 8 continued

Truck number	Date	$D_{max,}$ mm	Coarse aggregate reduction	Slump, mm	Delivery distance, km	Fiber type	Fiber content specified, kg/m^3	Mix type	Temp, °C	W/C ratio
11	21.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
12	21.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
13	21.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
14	21.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
15	21.9.09	16	28 %	210	6.5	HE 1/50	25	B30 M60 CI 0,1	No data	0,54
1	4.2.10	8	No data	200	25	Barchip	7	B35 M45 CI 0,1	22	No data
2	4.2.10	8	No data	200	25	Barchip	7	B35 M45 CI 0,1	22	No data
3	22.3.10	8	No data	200	25	Barchip	7	B35 M45 CI 0,1	20	No data
4	22.3.10	8	No data	200	25	Barchip	7	B35 M45 CI 0,1	20	No data
5	22.3.10	8	No data	200	25	Barchip	7	B35 M45 CI 0,1	20	No data
6	13.4.10	8	No data	200	25	Barchip	7	B35 M45 CI 0,1	No data	No data
7	13.4.10	8	No data	200	25	Barchip	7	B35 M45 CI 0,1	No data	No data
8	15.4.10	8	No data	200	25	Barchip	7	B35 M45 CI 0,1	No data	No data

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